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ORIGINAL CONTRIBUTION

Reinforcement Effect of Polypropylene Sheet on Soil Strength with Cement

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***Abstract*— Following thorough soil investigation, the designs for the foundations and other structures are made. The foundations and structures are more reliable and safer when the right soil is used. In this study, cement-coated Polypropylene (PP) sheets were employed to strengthen the soil, enhancing its shear strength and other characteristics. Two (2) soil samples were taken to compare the average outcomes and minimize error. Before using PP sheets for soil reinforcement, various index and strength parameters, such as breaking tensile strength, elastic modulus, and breaking and fusion points, among others, were examined. Properties like liquid and plastic limit, specific gravity, Maximum Dry Density (MDD), and Optimum Moisture Content (OMC) were examined as discussed. Reinforcement of 0%, 0.05%, 0.15%, and 0.25% were applied and tested against shear strength evaluation with the help of a direct shear test. An increase in strength is observed in soil samples 1 and 2, i.e., 1.27, 2.25, 2.27 and 1.28, 1.42, 1.65, and 1.79 in kg/cm^2, respectively. Similarly, unconfined compression strength was observed to increase from 0.0692 MPA to 0.0942 MPA, which is 11.68% and 35.94% increment in soil samples 1 and 2 at 0% and 0.05% reinforcement, respectively.**

***Index Terms*— Polypropylene (PP) Sheet, Cement, Soil Reinforcement, Soil Stabilization**

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I. INTRODUCTION

Expansive soils cause damage to several civil engineering structures, including spread footings, roads, highways, airport runways, and earth dams [1]. In the United States, the annual average damage from tornadoes, earthquakes, hurricanes, and floods combined is larger than the damage caused by expansive clays. Building on weak and soft soils offers a substantial risk due to their poor shear strength and extreme compressibility. By environmental challenges, researchers have been motivated to develop methods to enhance the strength qualities of geotechnical materials [2]. Research on rubber fibers or tire pieces as a substitute or recycled waste materials for soil enhancement has been extensive [3, 4, 5, 6]. In many geotechnical engineering applications, fiber reinforcing, particularly with local soils, has been acknowledged as a feasible approach for soil improvement. Numerous applications have used fiber reinforcement, including retaining wall backfill, stabilizing subgrades and subbases, boosting soil bearing capacity, reinforcing soft soil embankments, lowering soil hydraulic conductivity, improving erosion resistance, stopping piping leaks, and reducing shrinkage cracks [7, 8, 9, 10, 11, 12]. Tensile tensions are rendered mobile by friction between the reinforcements and the soil and can be supported by fiber reinforcements. Because tensile stresses are produced by dispersing shear stresses in soils through their tensile strength, the mobilization of tensile stresses in reinforcements frequently increases the shear strength of the soils [13]. Mechanical performance is improved in soils with randomly distributed polymeric additions, such as polypropylene (PP) and Polyethylene Terephthalate (PET). A range of synthetic and natural fibres are used in the fibre reinforcing approach to improve soil quality [14]. Some more prevalent artificial fibres are PVA, polypropylene, nylon, and carbon fibre. Longer fibres have been shown to perform better than shorter ones, and PVA fibre outperforms inert fibre. Longer fibres also improve the toughness and strength of fiber-reinforced clay [15]. Compared to polypropylene fibre, basalt fibre is more susceptible to freeze-thaw activity [16]. Freeze-thaw cycles reduce the UCS and ultrasonic pulse velocity of fiber-reinforced clay, according to Boz and Sezer [17]. According to Tomar et al. [18], polypropylene fibre reduces the growth of tension cracks on fiber-reinforced clay soil by acting as a reinforcing material and creating a bridge effect. According to Estabragh et al. [19], including nylon fibre enhanced the axial strain and UCS of clay, altering the failure modes from brittle to ductile. According to Gao et al. [20], carbon fibre reinforcement of clay considerably increased both the UCS and brittle failure, with a single carbon fibre having a one-dimensional effect and a network of fibres having a three-dimensional effect. Coir, hair, and basalt fibres are a few examples of common natural fibres. According to Gao et al. [15], the basalt fibre could increase the clay soil's unconfined compressive strength (UCS), and the

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optimum FC and FL values were 0.25 percent and 12 millimeters, respectively. Polypropylene fibre beat human hair and coir fibres in Basson and Ayothiraman's [21] experiment into the shrinkage cracking characteristics of fiber-reinforced clay soil. Fibre action changed the morphology and geometry of crack forms. Anggraini et al. [22] found that nano-modified coir fibres boosted the shear strength and durability of marine clay, with the tensile strength and friction between the surfaces acting as the main regulators of the reinforcing effect.

Another practical and cost-effective strategy has emerged in the form of fibre reinforcing growing subgrades. The potential of fibres to lengthen the lifespan of the stretched subgrades was thoroughly studied by many studies [23, 24, 25, 26]. Plastic waste polypropylene fibre has been successfully used as reinforcement [27, 28, 29, 30]. When reinforced with polypropylene fibres, expansive subgrades stabilized with silica fume had much better engineering qualities under freeze-thaw cycles [31]. When utilized to reinforce expansive subgrades, it was discovered that extending polypropylene fibre at the ideal moisture content enhanced the strength [32]. Numerous studies have examined the potential effects of combining various materials with the geogrid on sustainability, as noted. However, the combined impacts of geogrid and polypropylene fibre have not received much study attention. Insufficient research has been done on the interface behavior and shear strength characteristics of expansive subgrades reinforced with geogrid and polypropylene fibre. This study used a thorough experimental investigation to assess the combined reinforcing of fibres and geogrids. Large direct shear and free compressive strength tests were used to study the polypropylene fibre and the geogrid effect. Shear strength was calculated by centering the biaxial and triaxial geogrids and adding 0.25%, 0.50%, and 1.0% polypropylene fibre to the expanding subgrades.

The proposed project has the following objectives

- To study the reinforcement of soil
- To improve the bearing capacity of the soil
- To decrease the compressibility of soil at sight
- Use of waste polypropylene sheets in soil

II. MATERIALS AND METHODS

The following is the material used in this investigation.

1. Soil Sample-1
2. Soil Sample-II
3. Reinforcement: PP (Polypropylene) Sheets

The steps involved in the experimental work are as follows:

- Explicit soil gravity
- Atterberg limits

I. Liquid breaking point by utilizing casagrande instrument

II. Plastic limit

TABLE I
INDEX AND STRENGTH PARAMETERS OF PP SHEETS

S. No.	Behavior Parameters	Values
1	Fiber Type	Single Fiber
2	Unit Weight	0.91 g/cm^3
3	Average Diameter	0.034 mm
4	Average Length	12 mm
5	Breaking Tensile Strength	350 MPa
6	Modulus of Elasticity	3500 MPa
7	Fusion Point	165°C
8	Burning Point	590°C
9	Acid and Alkali Resistance	Very good
10	Dispersion	Excellent

1. Molecular length circulation by sifter assessment
2. Assurance of the Maximum Dry Density (MDD) and the related Optimum Moisture Content (OMC) of the soil with the guide of Proctor compaction investigate
3. Arrangement of fortified soil tests
4. Assurance of the shear strength by:

I. Direct shear test

II. Unconfined Pressure Test (UCS)

III. RESULTS AND DISCUSSION

Following are the results in tabular form and graphical representation.

A. Specific Gravity

TABLE II
SOIL SAMPLE-1 (SPECIFIC GRAVITY)

Sample Number	Specific Gravity	Avg. Specific Gravity
1	2.81	
2	2.62	2.72
3	2.73	

TABLE III
SOIL SAMPLE-2 (SPECIFIC GRAVITY)

Sample Number	Specific Gravity	Avg. Specific Gravity
1	2.58	
2	2.68	2.60
3	2.54	

The specific gravity results show that soil sample-1 will cause inorganic behavior, while soil sample-2 shows that it includes some porous material or organic matter, due to which soil can cause a little expansion.

B. Liquid Limit (LL)

TABLE IV
SOIL SAMPLE-1 (LIQUID LIMIT)

Sample Number	Water Content (%)	No. of blows
1	27.40	30
2	28.90	25
3	28.30	24
4	29.04	21
5	29.30	16

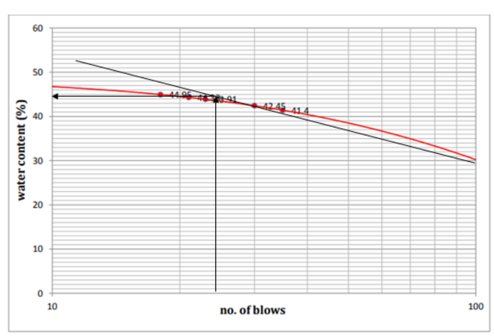

Fig. 1. Graphical Representation of Liquid Limit

C. Plastic Limit (PL)

TABLE V
SOIL SAMPLE-1 (PLASTIC LIMIT)

Sample Number	Plastic Limit	Avg. Plastic Limit
1	22.38	
2	23.43	22.60
3	21.94	

TABLE VI
SOIL SAMPLE-2 (PLASTIC LIMIT)

Sample Number	Plastic Limit	Avg. Plastic Limit
1	19.14	
2	20.41 3	19.56

D. Plasticity Index (PI)

Soil Sample – 1
PI = LL – PL = 28.88 – 22.60 = 6.30
Following USCS
Group: ML

Soil Sample – 2
PI = LL – PL = 43.89 – 19.49 = 24.41
In Accordance with USCS
Group: CL

The values of PI following the Unified Soil Classification System (USCS) show that the soil sample-1 lying in group ML shows the soil type to be silt with low plasticity, whereas the soil sample-2 lying in group CL shows the soil type to be clay with low plasticity.

E. Particle Size Distribution Curves

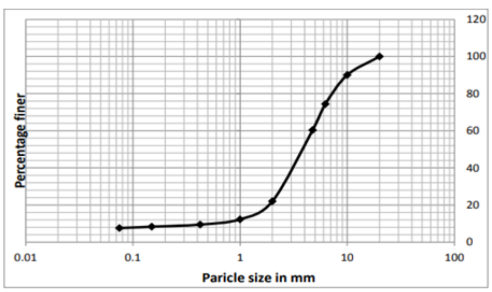

Fig. 2. Graphical representation of soil sample-1 (particle size distribution)

Coefficient of Uniformity = 7.9/5.8 = 1.362

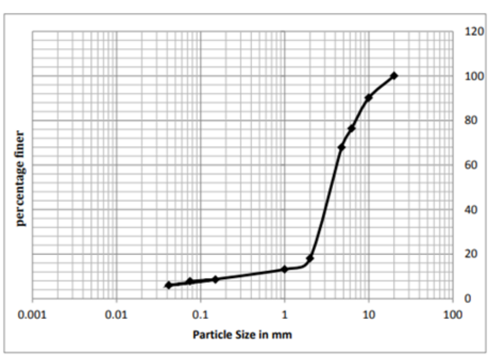

Fig. 3. Graphical representation of soil sample-2 (particle size distribution)

The gradation curves of both the soil samples (1 & 2) show that the particles present are mostly of the same size, which causes poor particles interlocking and ultimately leads to unwanted compaction.

Coefficient of Uniformity = 7.9/5.8 = 1.362

F. Standard Proctor Compaction

TABLE VII
SOIL SAMPLE-1 (PROCTOR COMPACTION TEST)

Sample Number	Water Content (%)	Dry Density (g/cc)
1	8.79	1.81
2	10.65	1.86
3	12.59	1.91
4	13.61	1.85
5	15.75	1.82

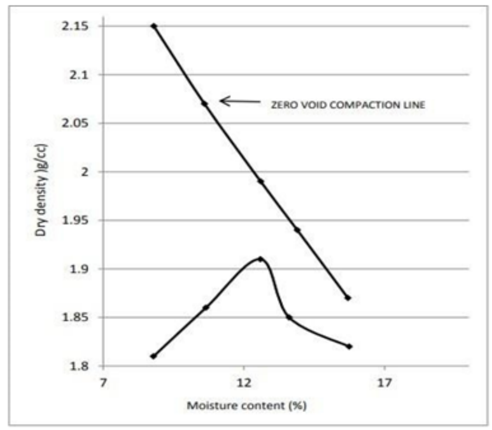

Fig. 4. Graphical representation of proctor compaction test

From the figure, it is obvious that
Content of Optimum Moisture (OMC) = 12.06%
Dry Density Maximum (MDD) = 1.91 g/cc

TABLE VIII
SOIL SAMPLE-2 (PROCTOR COMPACTION TEST)

Sample Number	Water Content (%)	Dry Density (g/cc)
1	12.18	1.79
2	14.40	1.86
3	17.02	1.96
4	18.11	1.87
5	21.03	1.83

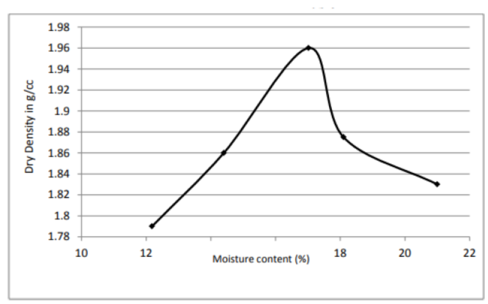

Fig. 5. Graphical representation of soil sample-2 (proctor compaction test)

From the figure, it is obvious that
Content of Optimum Moisture (OMC) = 17.02%
Dry Density Maximum (MDD) = 1.96 g/cc

G. Direct Shear Test

TABLE IX
SOIL SAMPLE-1 (DIRECT SHEAR TEST)

No.	Properties	Values
1	Shear box volume	90 cm^3
2	Soil maximum dry density	1.91 g/cc
3	Soil optimum moisture content	12.6 %
4	Soil weight in the shear box	1.91 × 90 = 171.9 grams
5	Water weight to be added	(12.59/100) × 171.9 = 21.66 grams

TABLE X
CONTROLLED SOIL SAMPLE (SOIL SAMPLE-1)

Sample Number	Normal Stress (kg/cm^2)	Proving Ring Reading	Shear Load (N)	Shear Load (Kg)	Shear Stress (Kg/cm^2)
1	0.5	54	206.58	21.06	0.59
2	1	84	321.35	32.76	0.91
3	1.5	106	405.51	41.34	1.14
4	2	168	451.42	46.02	1.27

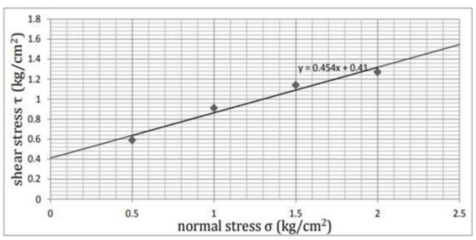

Fig. 6. Graphical representation of shear stress (soil sample-1)

Calculating from the graph,
Cohesion (C) = 0.326 kg/cm^2
Internal friction angle (Φ) = 47.71°

TABLE XI
REINFORCEMENT= 0.05% (SOIL SAMPLE-1)

Sample Number	Normal Stress (kg/cm^2)	Proving Ring Reading	Shear Load (N)	Shear Load (Kg)	Shear Stress (Kg/cm^2)
1	0.5	76	290.27	29.62	0.83
2	1	120	458.19	46.75	1.31
3	1.5	160	612.08	62.45	1.75
4	2	206	786.96	80.30	2.25

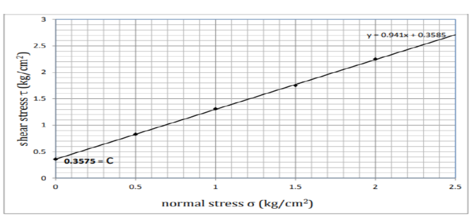

Fig. 7. Graphical representation of shear stress for soil sample-1 (reinforcement=0.05%)

Calculating from the graph,
Cohesion (C) = 0.3576 kg/cm^2
Internal friction angle (Φ) = 48.1°

TABLE XII
REINFORCEMENT=0.15% (SOIL SAMPLE-1)

Sample Number	Normal Stress (kg/cm^2)	Proving Ring Reading	Shear Load (N)	Shear Load (Kg)	Shear Stress (Kg/cm^2)
1	0.5	78	297.23	30.33	0.85
2	1	121	461.68	47.11	1.32
3	1.5	164	626.07	63.88	1.79
4	2	207	793.99	81.02	2.27

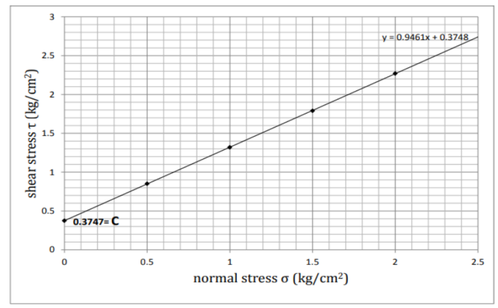

Fig. 8. Graphical representation of shear stress for soil sample-1 (reinforcement=0.15%)

Calculating from the graph,
Cohesion (C) = 0.3752 kg/cm^2
Internal friction angle (Φ) = 48.22°

TABLE XIII
REINFORCEMENT=0.25% (SOIL SAMPLE-1)

Sample Number	Normal Stress (kg/cm^2)	Proving Ring Reading	Shear Load (N)	Shear Load (Kg)	Shear Stress (Kg/cm^2)
1	0.5	7	300.79	30.69	0.86
2	1	122	468.64	47.82	1.34
3	1.5	166	636.61	64.96	1.82
4	2	209	800.95	81.73	2.29

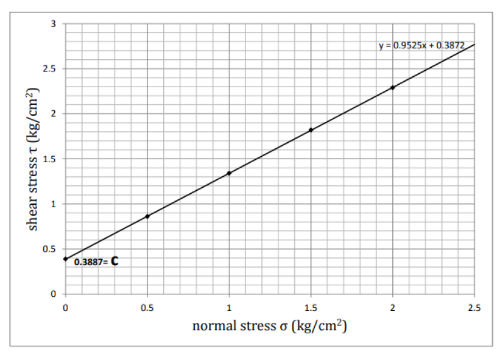

Fig. 9. Graphical representation of shear stress for soil sample-1 (reinforcement = 0.25%)

Calculating from the graph,
Cohesion (C) = 0.389 kg/cm^2
Internal friction angle (Φ) = 48.48°

TABLE XIV
SOIL SAMPLE-2 (SHEAR STRESS)

No.	Properties	Values
1	Shear box volume	90 cm^3
2	Soil maximum dry density	1.91 g/cc
3	Soil optimum moisture content	17.02 %
4	Soil weight in the shear box	1.96 × 90 = 176.4 gram
5	Water weight to be added	30.0238 gram

TABLE XV
CONTROLLED SOIL SAMPLE (SOIL SAMPLE-2)

Sample Number	Normal Stress (kg/cm^2)	Proving Ring Reading	Shear Load (N)	Shear Load (Kg)	Shear Stress (Kg/cm^2)
1	0.5	53	202.86	20.70	0.58
2	1	75	286.74	29.26	0.82
3	1.5	96	367.20	37.47	1.05
4	2	117	447.66	45.68	1.28

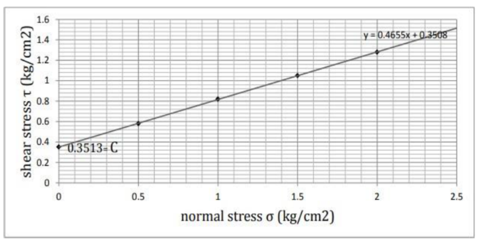

Fig. 10. Graphical representation of shear stress (soil sample-2)

Calculating from the graph,
Cohesion (C) = 0.352 kg/cm^2
Internal friction angle (Φ) = 27.79°

TABLE XVI
REINFORCEMENT = 0.05% (SOIL SAMPLE-2)

Sample Number	Normal Stress (kg/cm^2)	Proving Ring Reading	Shear Load (N)	Shear Load (Kg)	Shear Stress (Kg/cm^2)
1	0.5	66	252.11	25.70	0.72
2	1	88	336.09	34.26	0.96
3	1.5	111	427.13	43.54	1.22
4	2	130	497.17	50.68	1.42

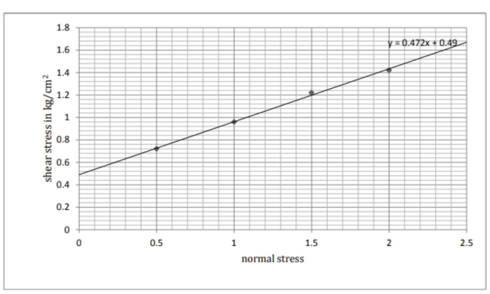

Fig. 11. Graphical representation of shear stress for sample-2 (reinforcement=0.05%)

Calculating from the graph,
Cohesion (C) = 0.4729 kg/cm^2
Internal friction angle (Φ) = 29°

TABLE XVII
REINFORCEMENT=0.15% (SOIL SAMPLE-2)

Sample Number	Normal Stress (kg/cm^2)	Proving Ring Reading	Shear Load (N)	Shear Load (Kg)	Shear Stress (Kg/cm^2)
1	0.5	72	275.46	28.11	0.788
2	1	99	378.75	38.65	1.083
3	1.5	126	482.05	49.19	1.378
4	2	151	577.70	58.93	1.651

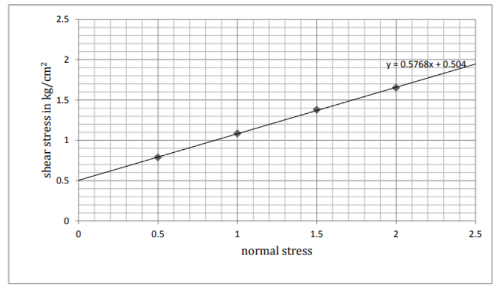

Fig. 12. Graphical representation of shear stress for soil sample-2 (reinforcement=0.15%)

Calculating from the graph,
Cohesion (C) = 0.501 kg/cm^2
Internal friction angle (Φ) = 29.91°

TABLE XVIII
REINFORCEMENT = 0.25% (SOIL SAMPLE-2)

Sample Number	Normal Stress (kg/cm^2)	Proving Ring Reading	Shear Load (N)	Shear Load (Kg)	Shear Stress (Kg/cm^2)
1	0.5	78	298.41	30.45	0.85
2	1	107	409.36	41.77	1.17
3	1.5	137	524.69	53.54	1.50
4	2	164	626.02	63.88	1.79

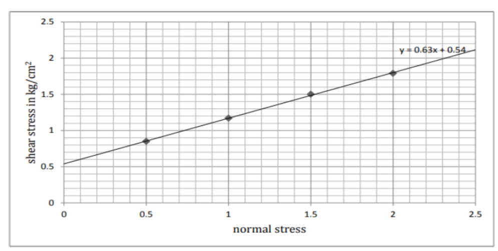

Fig. 13. Graphical representation of shear stress for soil sample-2 (reinforcement = 0.25%)

Calculating from the graph,
Cohesion (C) = 0.538 kg/cm^2
Internal friction angle (Φ) = 32.03°

H. Unconfined Compression Strength (UCS)

TABLE XIX
CONTROLLED SOIL SAMPLE (SOIL SAMPLE-1)

Dial Gauge Reading	Strain (ε)	Proving Ring Reading	Corrected Area	Load (N)	Axial Stress (MPa)
50	0.0033	35	19.72	40.81	0.0207
100	0.0067	62	19.82	69.19	0.0349
150	0.0100	79	19.92	92.11	0.0462
200	0.0133	91	20.03	106.12	0.0530
250	0.0167	98	20.13	114.27	0.0567
300	0.0200	93	20.24	108.44	0.0536
350	0.0233	85	20.34	99.11	0.0487

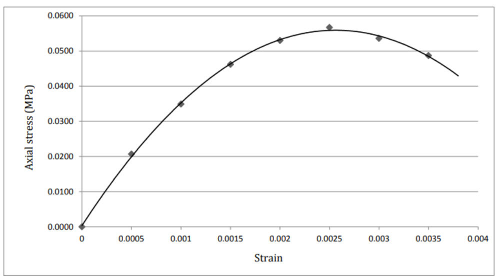

Fig. 14. Graphical representation of unconfined compression strength test (soil sample-1)

As attained from the graph UCS= 0.0562 MPa

TABLE XX
REINFORCEMENT = 0.05% (SOIL SAMPLE-1)

Dial Gauge Reading	Strain (ε)	Proving Ring Reading	Corrected Area	Load (N)	Axial Stress (MPa)
50	0.0033	48	19.72	55.97	0.0284
100	0.0067	65	19.82	75.79	0.0382
150	0.0100	93	19.92	108.44	0.0544
200	0.0133	102	20.03	118.93	0.0594
250	0.0167	109	20.13	127.09	0.0631
300	0.0200	105	20.24	122.43	0.0605
350	0.0233	96	20.34	111.94	0.0551

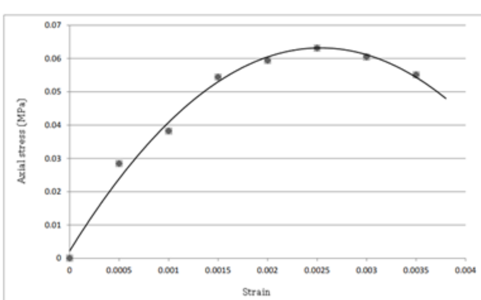

Fig. 15. Graphical representation of unconfined compression test for soil sample- 1 (reinforcement = 0.05)

As attained from the graph UCS = 0.0629 MPa

TABLE XXI
CONTROLLED SOIL SAMPLE (SOIL SAMPLE-2)

Dial Gauge Reading	Strain (ε)	Proving Ring Reading	Corrected Area	Load (N)	Axial Stress (MPa)
50	0.0033	42	19.72	48.97	0.0284
100	0.0067	78	19.82	90.95	0.0459
150	0.0100	102	19.92	118.93	0.0597
200	0.0133	114	20.03	132.92	0.0663
250	0.0167	119	20.13	138.75	0.0689
300	0.0200	115	20.24	134.09	0.0662
350	0.0233	107	20.34	124.76	0.0613

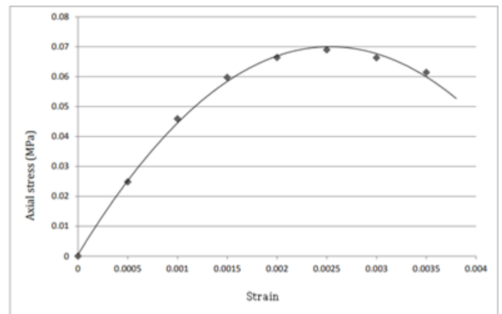

Fig. 16. Graphical representation of unconfined compression test for soil sample-2

As attained from the graph UCS = 0.0689 MPa

TABLE XXII
REINFORCEMENT = 0.05% (SOIL SAMPLE-2)

Dial Gauge Reading	Strain (ε)	Proving Ring Reading	Corrected Area	Load (N)	Axial Stress (MPa)
50	0.0033	63	19.72	73.46	0.0372
100	0.0067	105	19.82	122.43	0.0617
150	0.0100	120	19.92	151.58	0.0760
200	0.0133	154	20.03	179.56	0.0897
250	0.0167	162	20.13	188.89	0.0938
300	0.0200	155	20.24	180.73	0.0893
350	0.0233	142	20.34	165.57	0.0814

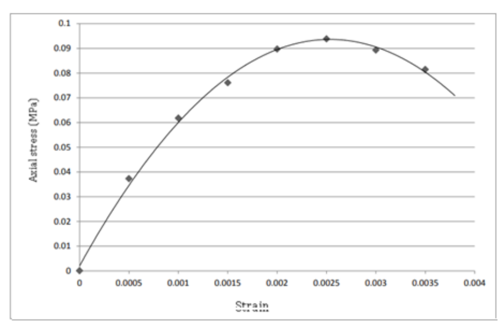

Fig. 17. Graphical representation of unconfined compression strength test for soil sample-2 (reinforcement=0.05%)

As attained from the graph UCS = 0.0942 MPa

IV. DISCUSSION

Results show the highest incremental values of the cohesion in soil sample-2, which is 34.70% at 0.005%, compared to soil sample-2, which is 0.8%, and a drastic decrease in values is observed as the fibers contents are increased up to 0.25%. At the same time, the % angle of internal friction of soil sample-2 is maximum at 0.25% fiber content and decreases as the fiber content % decreases.

In the same way, the values of % increment in UCS of soil sample-2 is maximum with 35.94 value against the fiber content % of 0.05% and decreasing with minimizing the % fiber content.

The summarized outcomes of the investigations and discussion above are shown in the graphical representation below:

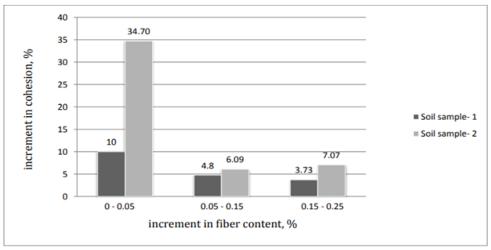

Fig. 18. Relation between % cohesion and % fiber content of soil sample-1 and soil sample-2

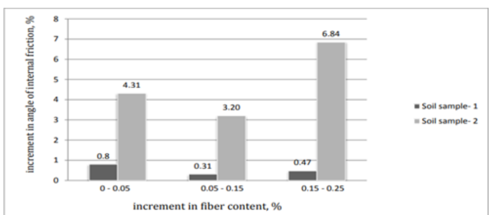

Fig. 19. Relation between % angle of internal friction and % fiber content of soil sample-1 and soil sample-2

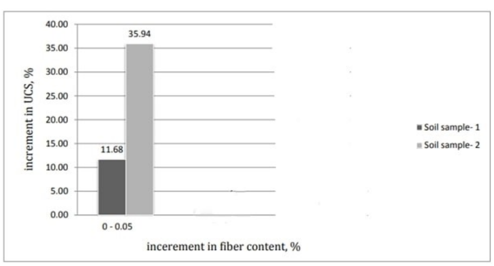

Fig. 20. Comparison of sample-1 and sample-2 for unconfined compression strength test

Results show the highest incremental values of the cohesion in soil sample-2, which is 34.70% at 0.005%, compared to soil sample-2, which is 0.8%, and a drastic decrease in values is observed as the fibers contents are increased up to 0.25%. Whereas the % angle of internal friction of soil sample-2 is maximum at 0.25% fiber content and decreases as the fiber content % decreases.

In the same way, the values of % increment in UCS of soil sample-2 is maximum with 35.94 value against the fiber content % of 0.05% and decreasing with minimizing the % fiber content.

V. CONCLUSION

In view of the current test study, the accompanying ends are drawn: The gradation curve shows that the soil samples are considered unsuited because the majority of the same-size particles cause weak compaction values because of poor bonding among the particles. In this way plasticity index range indicated the soil samples to be silt and clay with low plasticity. Also, looking at the outcomes from the UCS test for soil testing 2, it was tracked down that the UCS attributes showed a yield of 35.940% from 0.0691 MPa to 0.0942 MPa. This likewise builds up the past term that recommends using polypropylene sheets to fortify the soil as a soil test 2. It is often assumed that strand-strengthening soils can be considered an acceptable alternative to unconventional land improvements in creating weak soils that can replace strong/dense areas, reducing costs as a viable option.

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